LA-UR--85-2214

LA-UR--85-2214

DE85 014084

TITLE: MAPPING THE ENERGY SAVING POTENTIAL OF PASSIVE HEATING
COMBINED WITH CONSERVATION

DISCLAIMER

AUTHOR(S)   J. Douglas Balcomb

SUBMITTED TO   INTERSOL '85
Solar Energy Congress of the
International Solar Energy Society
June 23-29, 1985
Montreal, Quebec, CANADA

MASTER

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

MAPPING THE ENERGY SAVING POTENTIAL OF PASSIVE HEATING COMBINED WITH CONSERVATION*

J. Douglas Balcomb

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

ABSTRACT

A procedure is presented for estimating the energy savings potential of combining conservation and passive solar strategies to reduce building heating. General scaling laws are used for costs and the resulting continuous equations are evaluated to find the least life-cycle cost strategy. Results are mapped for the US.

INTRODUCTION

A methodology has been developed for determining the optimum mix between conservation and passive solar heating. The method has been used to develop US guidelines for insulation R-values, recommended infiltration rate, and the size of passive solar collection aperture [1]. The guidelines depend on the cost of fuel, economic factors, and the installed cost of passive solar and conservation features. The method has also been applied by the author in Portugal, Spain, Greece, and Mexico. The results vary widely, depending on the climate; for example, in cloudy areas conservation is the preferred strategy, while in sunny climates the balance shifts toward solar. However, in every case studied, a mix of strategies is recommended.

The purpose of this paper is to show the annual energy savings that would follow from the use of the recommended strategies. Energy savings are compared to a reference building insulated in accordance with standard practice prior to the oil embargo. A notable characteristic of these results is that energy savings are relatively constant over most of the northern US. The savings are quite large, in the range of 60-90 GJ for a 110 m^2 house, and represent a reduction of 75 to 90% compared with the reference building. In the southern US the relative savings are also large, but the absolute value is smaller because of the lower energy use of the reference building.

The basis for the optimization is minimizing the life cycle cost of the building. This cost is the sum of three components: (1) the initial cost of conservation, which is assumed to be inversely proportional to the building heat loss coefficient; (2) the initial cost of the passive solar features, which is assumed to be proportional to the net passive solar collection area; and (3) the future cost of fuel needed to heat the house, discounted to a present value. The annual heat required by the building is determined using the monthly solar load ratio (SLR) analysis procedure, which depends on the correlation of many hour-by-hour simulation analyses using typical meteorological year data from 26 cities representing an extreme variety of climates. The SLR procedure yields results that agree with the simulation results to within ± 4%. For this paper the passive system chosen is a sunspace with 50° sloping glazing inset into the south facade of the building. This is a good performer and is also a very popular design element. The equations are solved in closed form to yield compact analytical expressions for the optimum design parameters. The use of the SLR procedure allows us to estimate performance for the 209 locations where monthly weather and solar data are available and thus obtain the resolution needed to do mapping.

OPTIMIZATION

Cost Equations

Minimum life-cycle cost is the criterion used to determine conservation and solar values for each city. Life-cycle cost, LCC, is given by the formula

$$LCC = \text{system cost} + \text{fuel cost} . \tag{1}$$

Because each of these costs must be expressed in common terms, fuel cost is discounted to present value.

The system first cost is made up of portions ascribable to conservation and solar add-on costs; system cost $= C_s + C_c$. The solar first cost, C_s, is assumed to scale directly with system projected area:

$$C_s = a \, A_p , \tag{2}$$

where a = incremental passive-system cost per unit of projected area.

The conservation first cost, C_c, is assumed to depend inversely on the net load coefficient, NLC, as follows:

$$C_c = b/NLC - C_1 , \tag{3}$$

where b and C_1 are constants. The plausibility of this equation for the situation of discrete choices of conservation levels is discussed in Ref. 2.

The initial annual fuel cost is given by the formula:

$$\text{Fuel cost (first year)} = CH \cdot Q , \tag{4}$$

where Q = annual back-up heat required, and
CH = current cost of heat delivered into the building.

The annual back-up heat is given by the formula:

$$Q = NLC \cdot DD \cdot (1 - SSF) , \tag{5}$$

where DD = annual heating degree days and SSF is the solar savings fraction (this equation, in essence, defines SSF). Degree days should be determined for an appropriate base temperature calculated by subtracting the temperature difference due to internal gains from the thermostat setting.

To put future fuel costs in terms of an equivalent initial cost so that they may be fairly compared with system costs, a levelization factor, FF, and fixed charge rate, FCR, are used. The present value of the sum of all future fuel costs is given by

$$\text{Fuel cost (present value)} = CH \cdot Q \cdot FF/FCR \ . \tag{6}$$

The fixed charge rate, FCR, converts an initial cost to an equivalent annual cost. It should include not only direct effects such as interest on a mortgage, discount rate, and tax credits, but indirect effects stemming from deductions on interest payments, increased resale value of the solar system, property tax rates, and maintenance costs.

The levelization factor, FF, converts a current annual cost of heat into an equivalent annualized cost, accounting for the future cost of fuel (or electricity) and the discount rate. The current cost of heat should account for the efficiency of the back-up heater in converting fuel (or electricity) into useful delivered heat. See Ref. 3 for a discussion of fixed charge rate and levelization factor.

The life-cycle cost, LCC, in present-value terms, is the sum of the initial system costs and the present value of the future fuel costs, as follows:

$$LCC = a \, A_p + b/NLC - C_1 + h \cdot (1 - SSF) \cdot NLC \ , \tag{7}$$

where

$$h = (CH \cdot FF \cdot DD)/FCR. \tag{8}$$

Minimum Life Cycle Cost

If LCC is minimized independently with respect to A_p and NLC, it follows that the following two equations must be satisfied:

$$D = a/h \ , \tag{9}$$

and

$$NLC = \sqrt{\frac{b}{a(1/LCR + (1 - SSF)/D)}} \ , \tag{10}$$

where

$$D = d(SSF)/d(1/LCR) \tag{11}$$

(derivative of SSF with respect to 1/LCR).

A solution is obtained by iteration, beginning with a guess for LCR, since SSF is a function of LCR in the monthly SLR method. The equation for NLC, used alone, balances conservation and solar to minimize annual auxiliary for a fixed initial investment. Equation (9), used alone, optimizes the size of the solar system.

ASSUMPTIONS

System Type

The user may specify the passive system type, which establishes the relationship between SSF and LCR, and any cost parameters desired. We have chosen to use a semi-enclosed sunspace identified in Ref. 1 as system type SSD1. The glazing is double and is oriented due south at a 50° slope. The sunspace back wall is massive.

Costs

Cost values assumed are as follows:

$$a = 108 \ \$/m^2$$
$$b = 530,000 \ \$/4/°C \text{ for a } 110 \ m^2 \text{ house}$$
$$CH = 21 \ \$/10^9 J \text{ (electric heat)}$$
$$FCR = 0.1$$
$$FF = 1.5$$
$$\text{Thermostat setpoint} = 21.1°C$$
$$\text{Internal Gains} = 5.9 \ W/m^2$$

Conventional Construction

To determine energy savings, we must establish a reference house of conventional construction. Pre-oil embargo conservation levels varied widely, but were generally greater in colder climates. We chose a value of wall insulation as follows:

$$RSI = 0.026 \ \sqrt{(\text{degree days, base } 18°C)} \ , \tag{12}$$

and other conservation levels chosen proportionally so that building loss coefficient varies as $1/\sqrt{DD}$. This follows directly from the assumption that convention construction had been optimized over the years for a fuel cost of \$2.10 $\$/10^9 J$ (assuming a 66% fuel conversion efficiency to heat). The result is

$$NLC = 17500/\sqrt{DD} \ , \ W/°C \tag{13}$$

for conventional construction for a 110 m^2 house. The annual energy used by the conventional house is:

$$Q = 86400 \ (NLC)(DD), \ J \tag{14}$$

RESULTS

The figure shows a map of the resulting energy savings for the US for a 110-m^2 house. The map is based on interpolation between discrete calculations performed for 209 weather data locations in the US. Corresponding values for LCR, SSF, and wall R-values can be found in Ref. 1. Conservation levels that result from the optimization vary from wall insulation RSI-1 to RSI-6 (R5 to R35) across the US, depending primarily on heating degree days and to a lesser extend on solar availability. Other conservation levels vary proportionally. The passive solar glazing area varies from 5% of the building floor area near the Great Lakes to 28% in the colder and sunnier regions of the intermountain west.

This methodology has also been used to develop design guidelines. The guidelines are of greatest use early in the design process. Although this approach makes broad-brush assumptions, it is very useful in obtaining a general feel for how strategies vary and the general level of performance that can be achieved economically.

REFERENCES

1.   J. D. Balcomb, R. W. Jones, R. D. McFarland, and W. O. Wray, Passive Solar Heating Analysis, published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, Georgia (1984).

2.   J. D. Balcomb, "Conservation and Solar: Working Together," Proc. of the 5th National Passive Solar Conference, Amherst, Massachusetts, October 19-26, 1980, pp. 44-50 (LA-UR-80-2330).

3.   J. D. Balcomb, C. D. Barley, R. D. McFarland, J. E. Perry, Jr., W. O. Wray, and S. Noll, Passive Solar Design Handbook Vol. II, US Department of Energy report DOE/CS-0127/2 (January 1980).
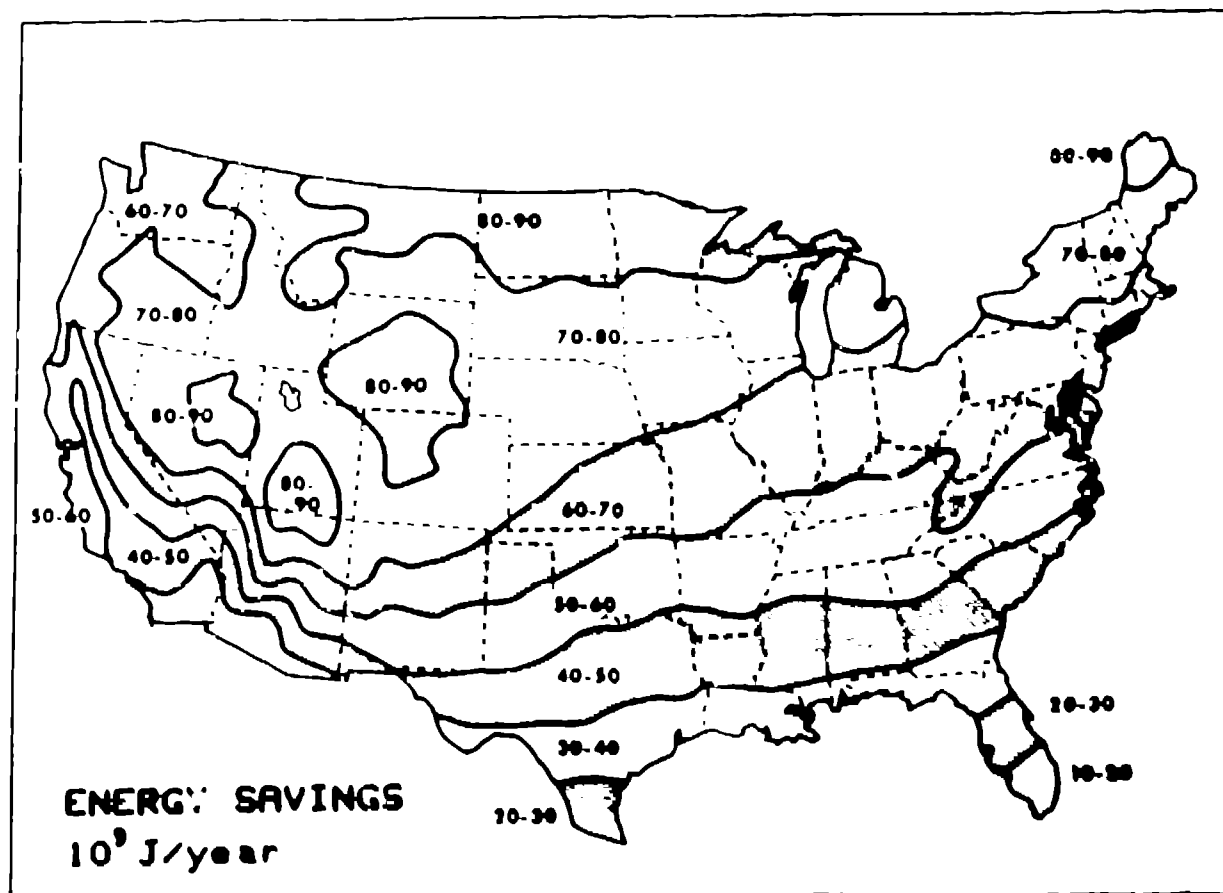
Fig. 1.   Annual savings, due to conservation and solar combined, for a 110 m² house compared with a nonsolar house of conventional construction.